BTO Transactive Portfolio at PNNL

Pacific Northwest National Laboratory

Dennis Stiles

April 17, 2019

Program History at PNNL

OE: Pioneering Transactive Experiments

OE & BTO Partnership To Enable A Transactive Energy System

ENERGY.GOV
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY
Building Technologies Office

Behind-the-meter & Across-the-meter Transactive At Scale

Control Methodology Development

Distributed Control Platform Development

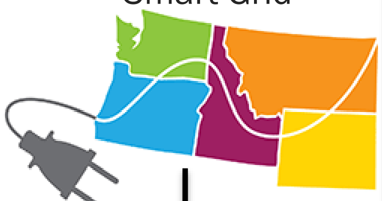
Valuation Methodology Development

AEP *gridSMART*

AEP OHIO
A unit of American Electric Power

GridWise Experiment

Pacific Northwest Smart Grid



2005 **2010** **2013** **2014-18** **2019→**

OE Transactive Portfolio At PNNL

OE Transactive System Program Objectives:

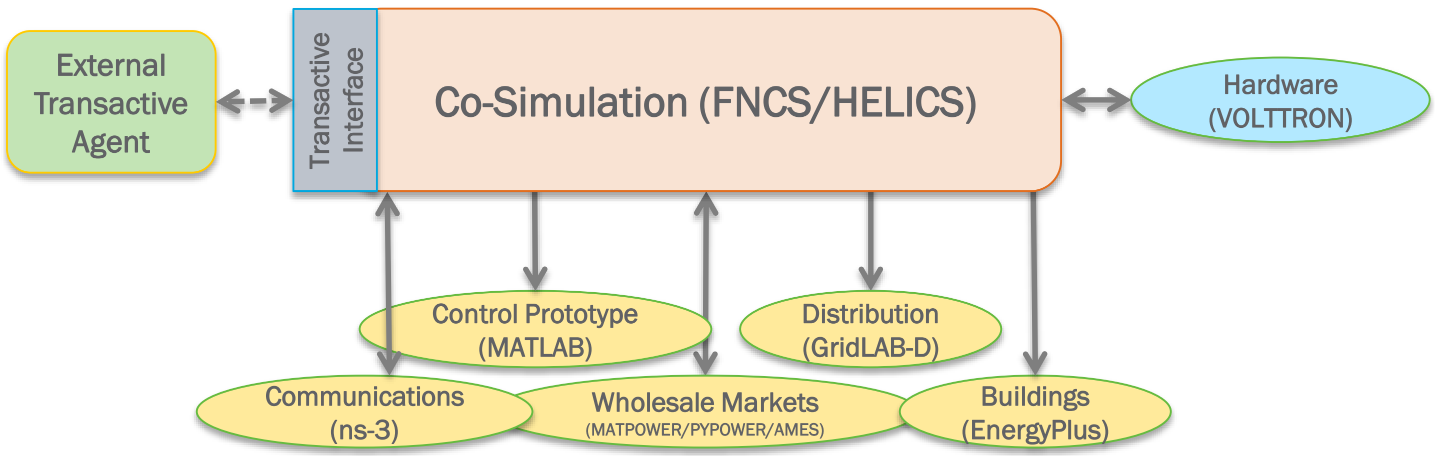
- Manage large-scale deployments of distributed assets
- Use decentralized decision-making approaches: scalability, privacy, choice
- Use value-based incentives to coordinate resources voluntarily
- Provide the smooth, stable, predictable response required for reliable, resilient system operations
- Establish a transactive energy community and path to commercial adoption

Research Project Portfolio at PNNL:

- Valuation
- Simulation & Modeling
- Theory
- Architecture, Interoperability & Outreach
- Path to application:
  - DSO+T system study
  - Partnering with BTO on the Transactive Campus project
  - Resilient distribution system engaging PV and commercial building loads

Co-Simulation Effort Will Provide Another Key Platform

- Scenario template (system challenge and use cases) for configuring simulation
- Support transactive agent integration and capture data for valuations
- Extensible in scale and capability
- Open source



BTO Transactive Portfolio At PNNL

Objective: provide technologies that address the challenges of:

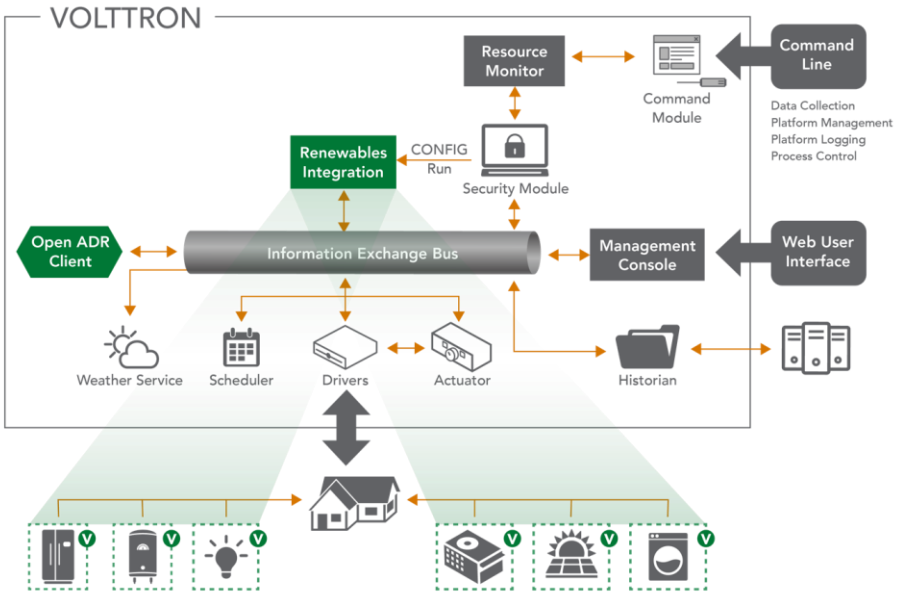
- ***dynamically coordinating*** large numbers of building loads and associated distributed energy resources (e.g., on-site generation, batteries, thermal storage) with the grid
- ***while maintaining* comfort** and other building services, and ***maintaining local autonomy*** over the asset response
- enable this coordination ***at a scale and cost*** compatible with DOE goals (grid reliability & resiliency, integration of new resources, affordability, storage)

Research Project Portfolio At PNNL:

- Quantification of Flexible Load Potential
- Scaling of Commercial Building Transactive Control & Coordination (Campus Project)
- Connected Homes
- Pliant Permissive Priority Optimization

Enabling Technology Developed Early in the BTO Transactive Effort: The VOLTTRON™ Platform

- Reference platform for distributed, agent-based control
- Python-based, deployable on affordable commodity hardware
- Domain independent platform for connecting applications via a common message bus
- Flexible environment providing services for data collection and storage
- Secure
- Growing community from academia, national labs, and industry



U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Quantification of Flexible Load Potential

Pacific Northwest National Laboratory

Di Wu, Ph.D.

Project Plan

Year 1 (completed)

- Performed a national opportunity assessment to quantify the potential (GW/GWh) from building loads
- Developed characterization methods, including both analytical and optimization-based methods
- Completed a preliminary benefit assessment study for California

Year 2 (completed)

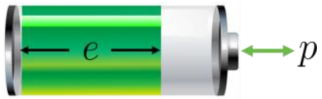
- Developed a regional flexibility potential assessment tool
- Performed Locational Net-Benefit Analysis and case study using distribution systems within SCE
- Integrated battery-equivalent model and assessment into NRECA OMF

Year 3 (in progress)

- Design and test optimal scheduling strategies for residential building assets to provide multiple grid services
- Implement and evaluate optimal scheduling strategies within NRECA's utilities and cooperatives.

Characterization Methodology

Virtual battery-based representation for an aggregation of resources



VB dynamics:

$$\frac{de(t)}{dt} = -ae(t) + p(t)$$

P & E ranges:

$$P^{\min}(t) \le p(t) \le P^{\max}(t)$$

$$E^{\min}(t) \le e(t) \le E^{\max}(t)$$

Variable and parameters:

- $p(t)$ is the charging/discharging power
- $e(t)$ is the energy state
- $P^{\min}(t)$ and $P^{\max}(t)$ are the lower and upper power limits, respectively
- $E^{\min}(t)$ and $E^{\max}(t)$ are the its lower and upper energy limits, respectively
- a is the self-discharge rate

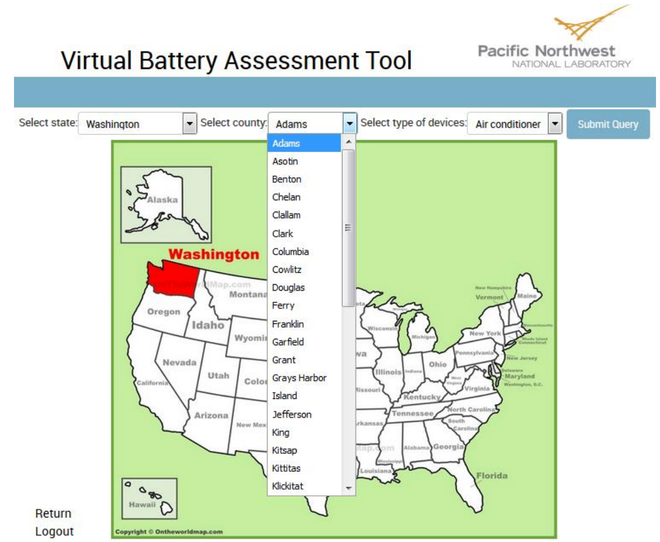
Developed methods to estimate time-varying power and energy ranges

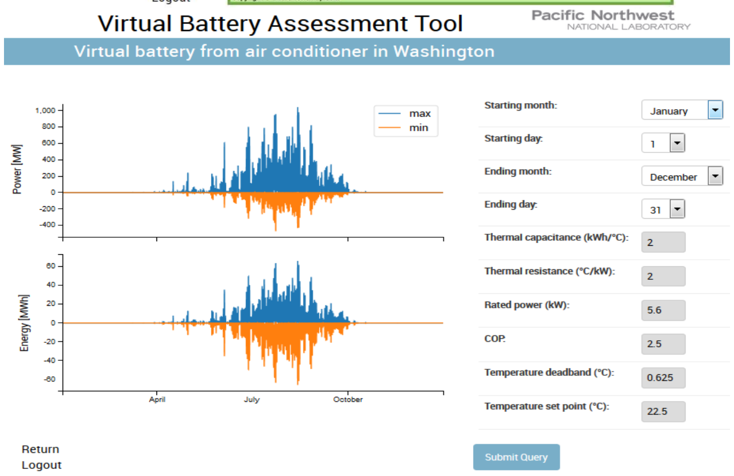
- Analytical method
- Optimization-based method

[1] D. Wu, H. Hao, T. Fu, and K. Kalsi, "Regional assessment of virtual battery potential from building loads," in *Proceedings of the IEEE Power and Energy Society Transmission and Distribution Conference and Exposition*, Apr. 2018, pp. 1–5.
[2] H. Hao, D. Wu, J. Lian, and T. Yang, "Optimal coordination of building loads and energy storage for power grid and end user services," *IEEE Transactions on Smart Grid*, vol. 9, no. 5, pp. 4335–4345, Sep. 2018.

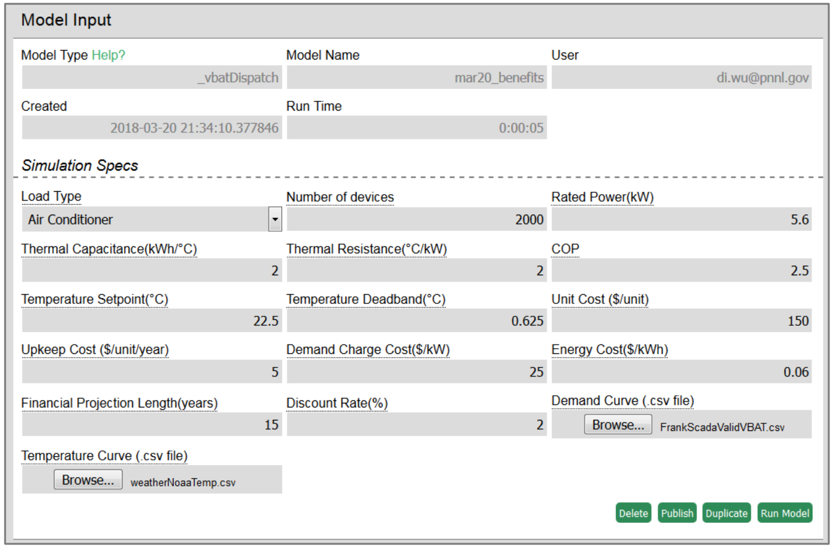
Assessment Tool

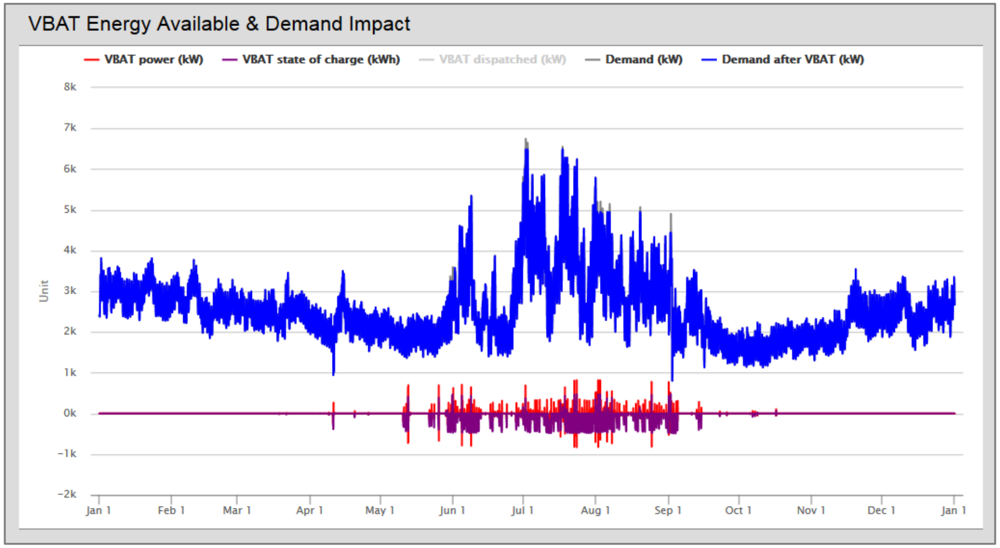
- An interactive web application (http://35.162.145.49/index/)
- Regional VB potential depends on:
  - Resource type (residential air conditioners, water heaters, commercial HVAC, etc.)
  - Number of resources
  - Parameter values for the population (thermal resistance and capacitance, COP, etc.)
  - External drivers such as ambient temperature, water draw, usage patterns, etc.





Evaluation and Dispatch Applications in OMF





Potential Evaluation App

- https://www.omf.coop/newModel/vbatEvaluation/btoOct2018

Dispatch Cost-Benefit Analysis App

- https://www.omf.coop/newModel/vbatDispatch/btoOct2018dispatch

Scaling of Building Transactive Control and Coordination to Support Grid Operations

Pacific Northwest National Laboratory

Srinivas Katipamula, Ph.D.

Project Contributors

Project Team: Srinivas Katipamula, Robert Lutes, Sen Huang, Ronald Underhill, Hung Ngo, Don Hammerstrom, Saptarshi Bhattacharya, Jamie Lian, Di Wu, Ke Ma, Steve Widergren, Karan Kalsi and Dennis Stiles

Project Administrator: Jamie Spangle

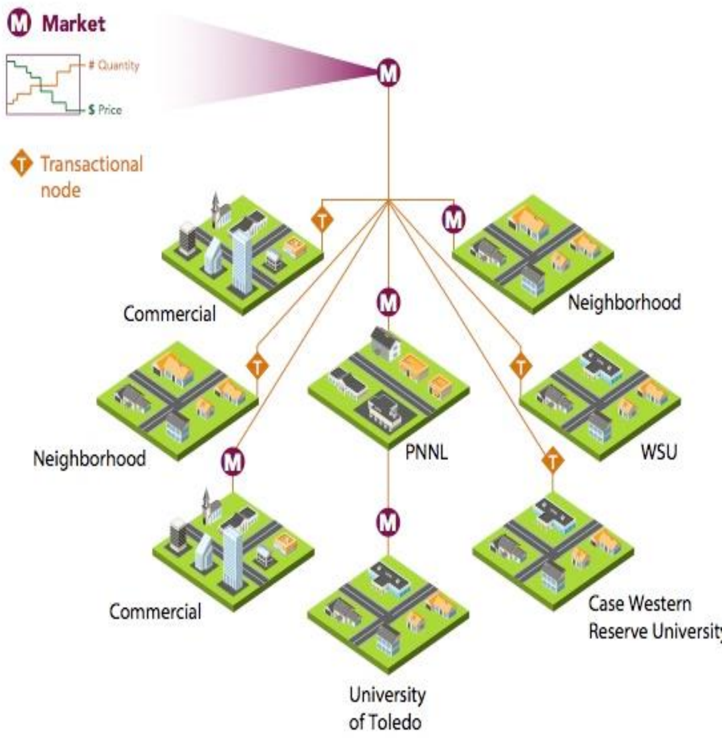
PNNL Facilities and Operations staff

Technical Advisory Committee:

- **Utilities**: Joe Hagerman, NRECA; Arunkumar Vedhathiri, National Grid; John Gibson, Avista; Uzma Siddiqi, Seattle City Light; Brian Kolts and James Jirousek, First Energy;
- **R&D**: Wu Xiaofan, Siemens;
- **SGO and NGO**: Robin Roy, Next Energy; Joseph Borowiec, NYSERDA;
- **Energy Service Providers**: Terry Herr, Intellimation; Hugh Henderson, Frontier Energy;
- **Universities**: Dustin McLarty, WSU; Mike Heben, University of Toledo; Brian Hutchinson, Western Washington University; Jin Wen, Drexel University
- **DOE**: Erika Gupta, EERE; Chris Irwin, OE

Scaling of Building Transactive Control and Coordination to Support Grid Operations

- **What:**
  - Develop and validate a scalable multi-layered transactive control and coordination (TCC) reference design to support reliability and resilience of the power grid
- **Why:**
  - To support significant penetration of renewable generation (>20% of the total system load)
  - To show that there is a more efficient solution to mitigate the supply-demand imbalance and to absorb variability and uncertainty of renewable energy generation using DERs as opposed to reserve generation



Project Approach

How:

– Applying new control theory, combined with market concepts, to encourage competition amongst controlled devices for “commodities”

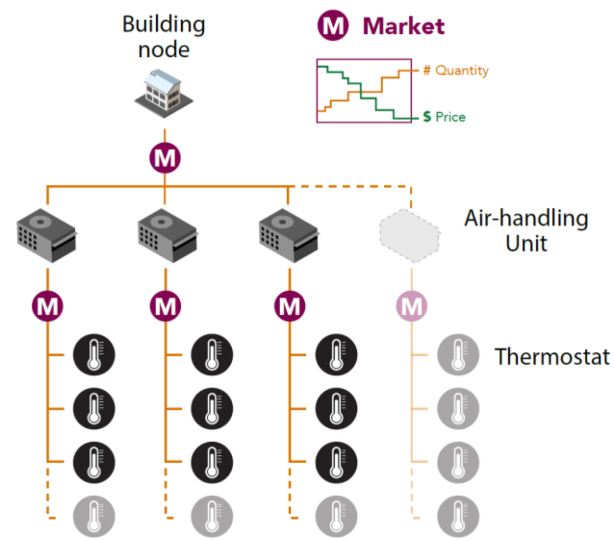
– Where each controlled device is represented by an “agent,” which is self-interested and maximizes its benefit

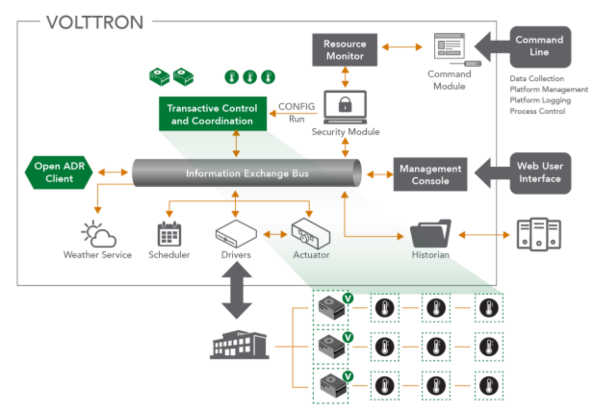
– Agents bid for the commodities based on their flexibility by maximizing “profit” while maintaining service levels

– Highly automated process to achieve scalability and delivered using VOLTTRON™ – a distributed sensing and controls platform

– Initially, proving scalability in a simulation environment, followed by testing in multiple buildings on multiple campuses

– Finally, working with utility partner(s) to evaluate scalability of our reference design and define a field test

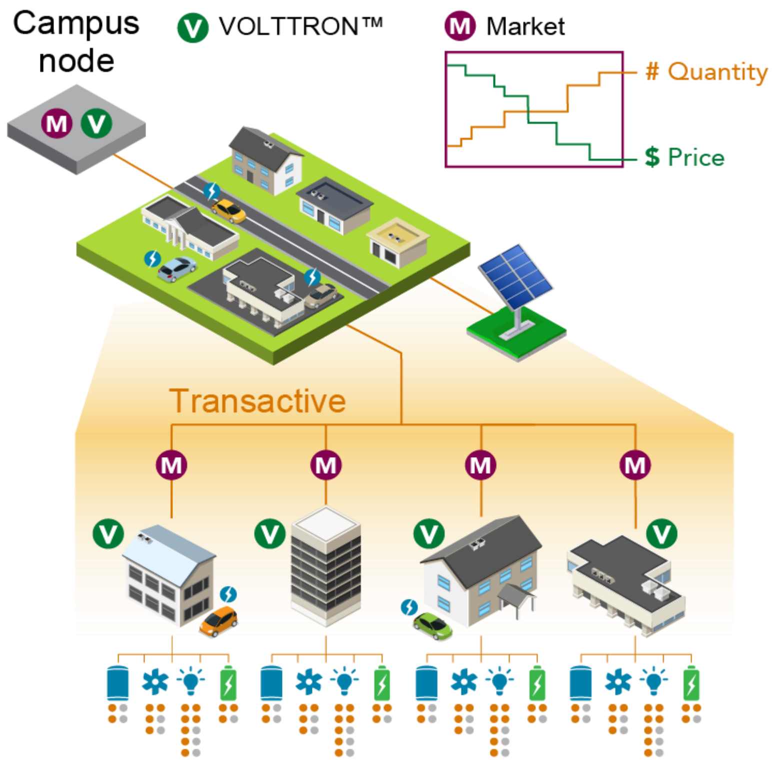




Project Outcomes

Result:

- Creation of a template or "recipe for replication" of TC services for better and integrated control of DERs to help building owners and aggregators easily replicate and scale TC services
- Reduction in operating costs between 10% and 20%, while maintaining service levels and supporting grid reliability and resiliency
- Release all software as open source



Project Approach

FY19	FY20	FY21
1. Project coordination, including forming a technical advisory panel (TAC) 2. Complete development of ILC/TCC 1.0 technology 3. Complete design, development and testing of transactive controls for BESS and TESS 4. Enhance ILC and TCC technologies for scalable deployment – version 2.0 5. Test enhancements of ILC 2.0 and TCC 2.0 in simulation environment 6. Deploy ILC 1.0/2.0 and TCC 1.0/2.0 in buildings at partner sites 7. Generalize and extend market clearing mechanism	8. Test ILC 2.0 and TCC 2.0 in multiple buildings across multiple campuses 9. Working with TAC, utility partner, and project partners, develop a detailed field-test plan 10. Document technologies, draft user guides/cookbook for replication 11. Prepare technology package for field testing 12. Recruit energy-service providers	13. Launch field test of TC technologies (TCC 2.0 and ILC 2.0) in a utility territory 14. Prepare replication template 15. Draft final report

Integrate TAC across all activities

Project Objectives

Eight key objectives for achieving the project goal are:

- Solution will be applicable to
  - O1: Both existing and new buildings and buildings with and without building automation systems
  - O2: A wide range of DERs
- O3: Demonstrate scalability of multi-layered TCC technologies tailored for low-cost embedded computers and controllers
- O4: Support current utility demand-response and future transactive services
- O5: Solutions will be tailored for both individual building owners or aggregators
- O6: Accelerate the rate of return on hardware investments and ongoing operational costs and services that advance GSs
- O7: Ultimately, develop a template for replication by individual building owners or aggregators
- O8: Engage energy-service providers on how to deploy the technologies in the field

Connected Homes

Oak Ridge National Laboratory

NRECA America's Electric Cooperatives

SkyCentrics

Vectren Live Smart

University of Colorado Boulder

Boulder Housing Partners

The University of Oklahoma

Pacific Northwest National Laboratory

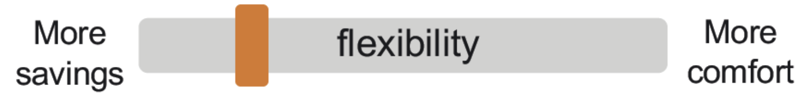
Nora Wang, Ph.D.

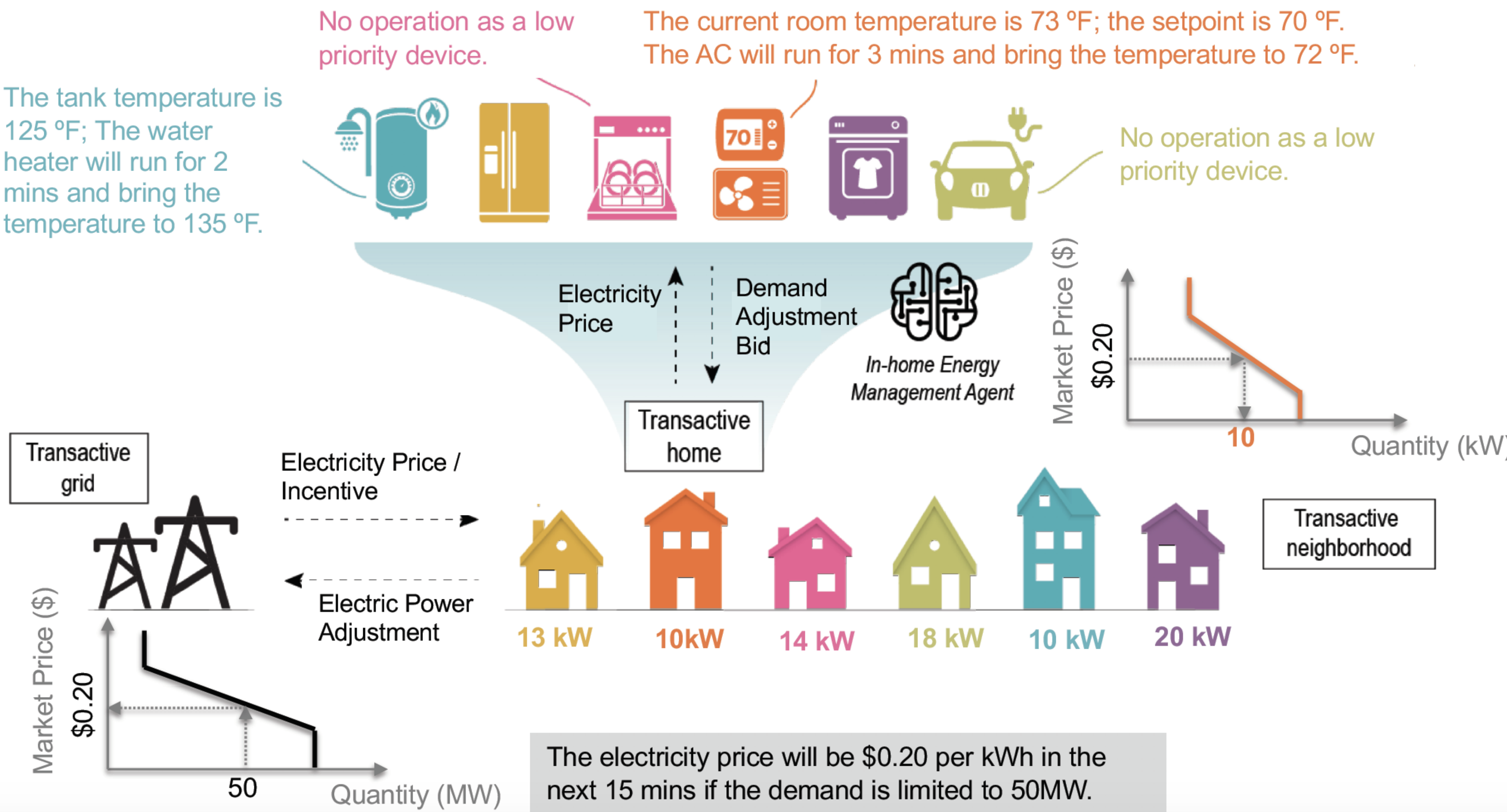
Planned Outcomes

- **A prototype system** tested in occupied homes and a reference design for commercializers to use in creating products with similar capabilities.
  - System mostly sets itself up—Minimal installation, information entry, and other set up actions by the customer
  - Operates reliably over years without faults (months to a year for the project prototypes)
  - Captures the unique device and home thermal behaviors
  - Accommodates actual device and communication behavioral limitations (e.g., latency in communications)
  - Compatible with many different smart communicating devices from different vendors and potentially non-smart devices
- **Quantified demand response impacts,** based on findings from tests in real homes, of 10% or more decreases in the “normal” power load of connected appliances participating in demand response

TCC for Connected Homes

Each connected device (e.g. T-stat) has its flexibility setting (reflecting user priority), based on which a unique price curve (price / T setpoint) is used to control device operation (kW, kWh) in the next 15 mins.

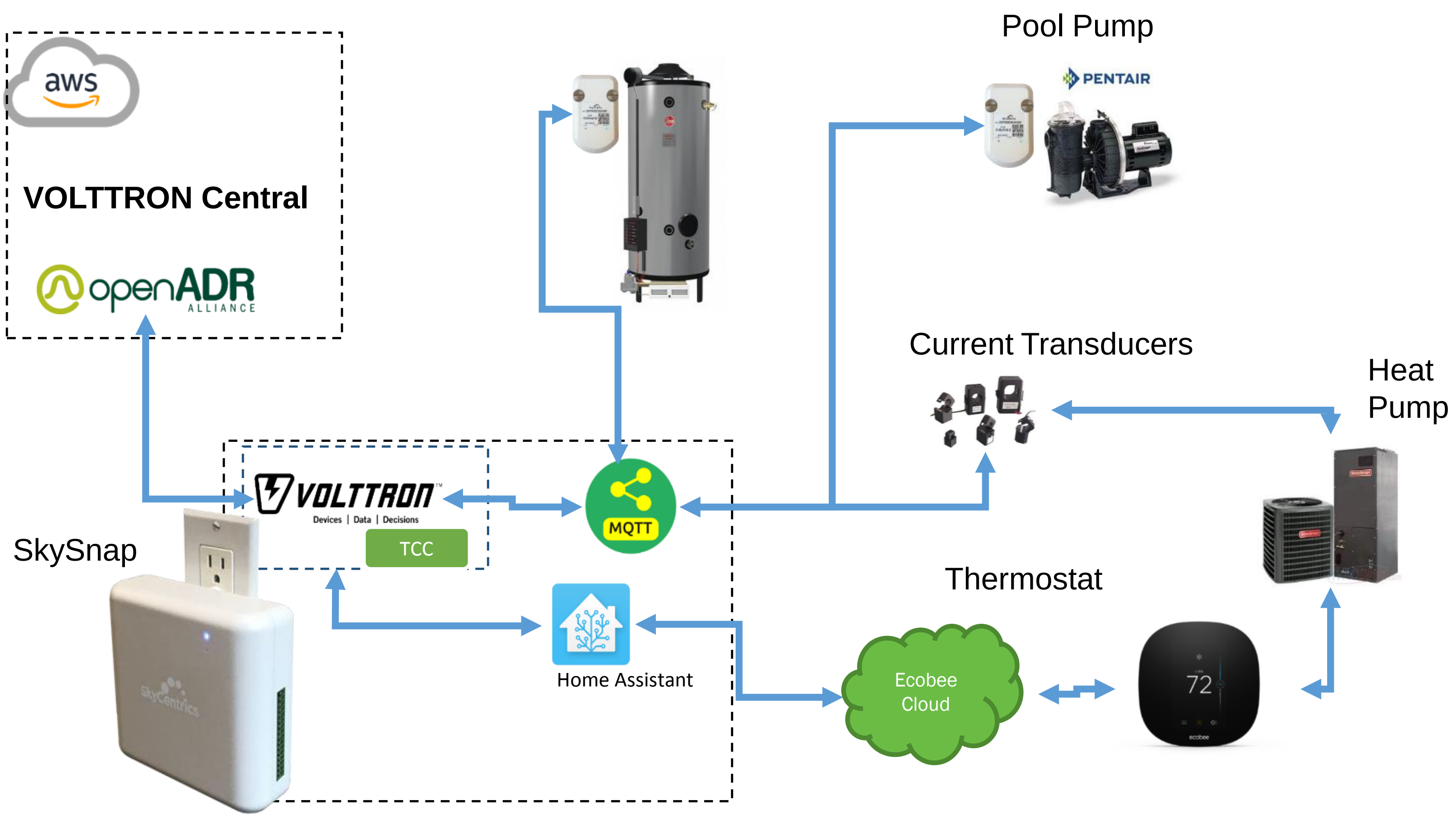




Three-Year Project Plan (FY19-21)

- Task 1: Data-driven device models and transactive-based HEM control
  - Progressively develop and test interim versions of the control solution in stages starting with a single device type (e.g., heat pumps and air conditioners) and adding devices incrementally, one or two at a time
- Task 2: VOLTTRON-based prototype platform
  - Develop a flexible hardware and open software platform on which to implement the transactive control solution
- Task 3: Test the prototype system in PNNL Lab Homes
  - Implement control for each device in software modules and integrate them into the platform for testing and validation under a wide range of conditions (e.g., weather and occupant behaviors) and target demand response levels
- Task 4: Test and validate the prototype in real homes
  - Test in occupied sample homes in support of development and to validate final performance.
  - 5 sample homes for initial testing of heating and air-conditioning control
  - Partners: University of Colorado, University of Oklahoma, NRECA, National Grid, Vectren

Prototype Structure



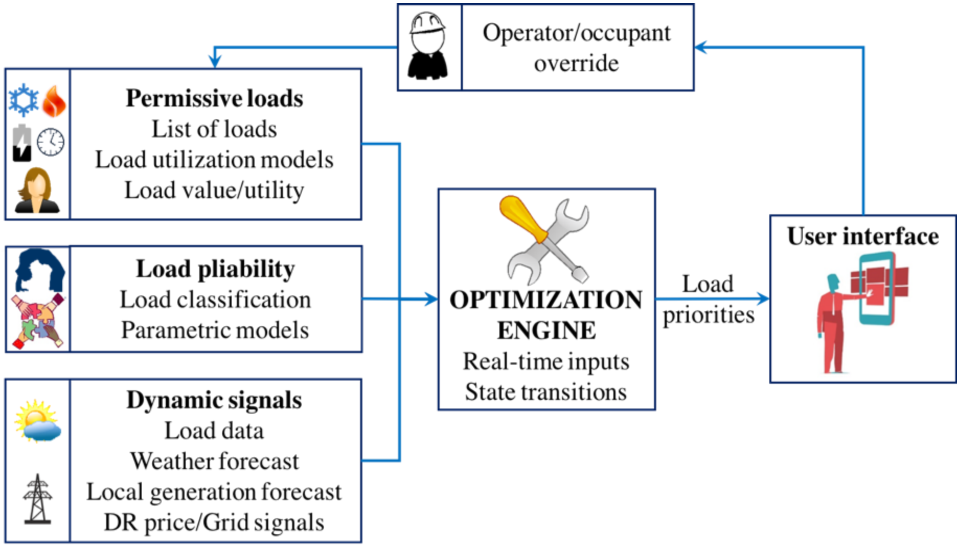
Pliant Permissive Priority Optimization

Pacific Northwest National Laboratory

Draguna Vrabie, Ph.D.

Pliant Permissive Priority Optimization

- Develop an app where, at installation, the building owner lists all assets and data sources associated with their power consumption and controls.
- App learns availability models for building assets from utilization data.
- App ranks flexible assets in real-time based on their predicted availability and pliability.
- App computes maximal expected value from building-grid service participation based on grid signals and asset pliability, with minimal risk of affecting end-use
- App provides reports to asset owner on utilization, expected value of participation and grid service programs, and expected return on investment from building-grid controls.
- Test app capabilities with high fidelity building simulation models

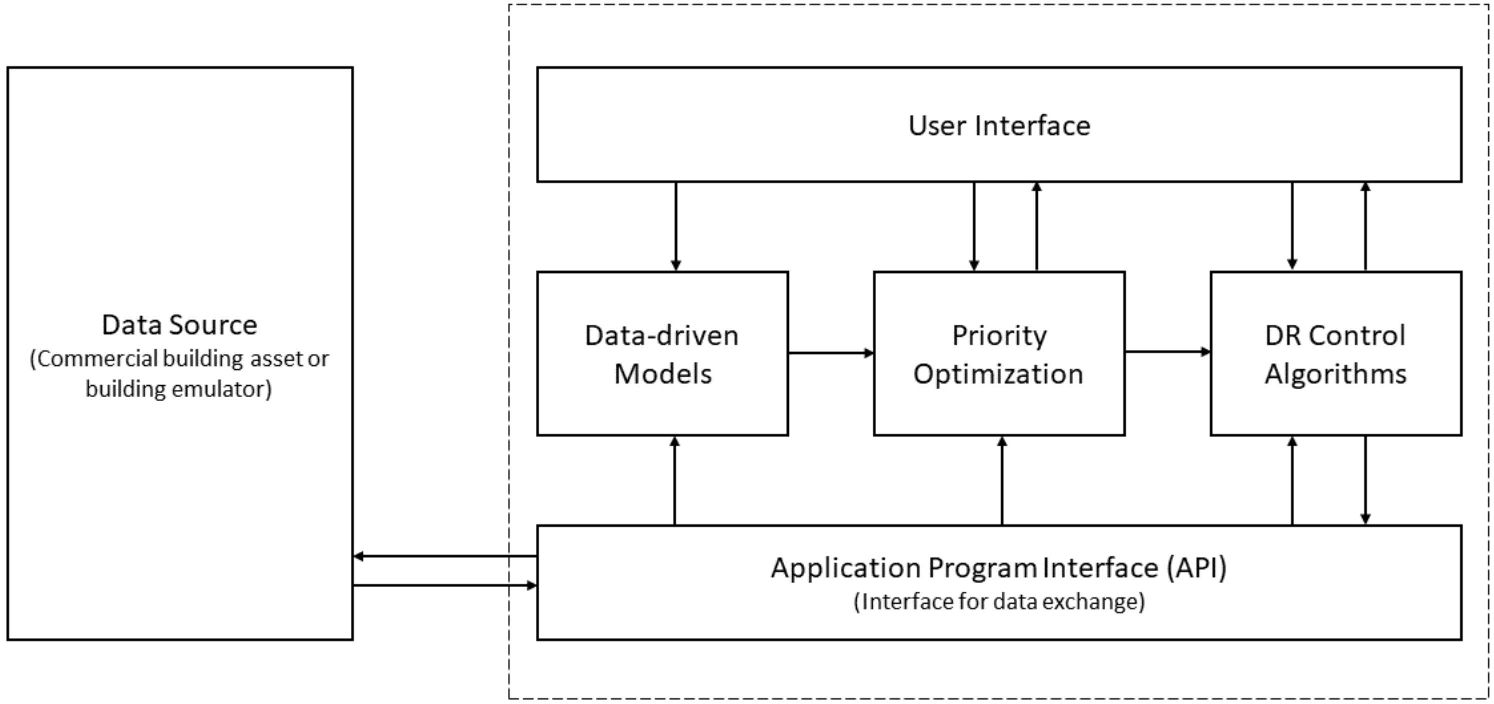


Framework to dynamically value and classify building loads

Load Prioritization Framework

Technical Elements

- Data-driven modeling of asset availability
- Asset ranking under uncertainty, accounting for stakeholder input, with adaptive ability to user behavior



Asset Prioritization under Uncertainty

Rank assets based on their potential maximal value from participation in grid-oriented activity when assets are subject to random utilization by building occupants

Objective: maximize expected reward for participating in grid services

Decisions: binary decision for each device to be selected for participation in a available grid service

Constraints:

- device availability
- device flexibility
- value of participation
- risk of impact to occupants

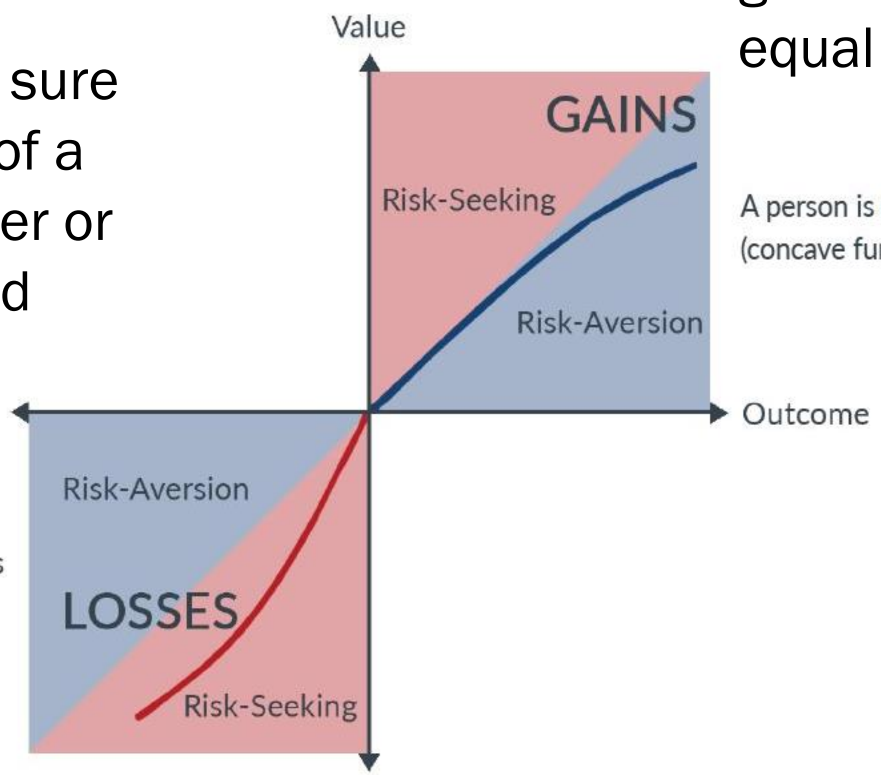
Output: Asset ranking based on expected rewards from grid service participation

Accounting for Human Preferences

Prospect Theory: The Value Function

Preference for a sure outcome over a gamble with higher or equal expected value

Rejection of a sure thing in favor of a gamble of lower or equal expected value



A person is risk-averse for gains (concave function)

A person is risk-seeking for losses (convex function)

Source: Kahneman, D., & Tversky, A. (1979). Prospect Theory: An Analysis of Decision under Risk. Econometrica, 47(2), 263-291.

Performance Testing in Virtual Environments

Large commercial building

Occupancy behavior models

Occupancy (presence) models
serve as input of other models

→ **Light switching models**
outdoor illuminance & occupant behavior

→ **Thermostat adjustment models**
rely heavily on data

→ **Appliance use models**
Monte Carlo simulations

Medium-size commercial building

Net Zero Energy Community

Thank You